The Design of Lucida®: an Integrated Family of Types for Electronic Literacy

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ABSTRACT

Electronic printing and publishing transform traditional analog letterforms into digital pixel patterns. At medium and low resolutions, aliasing degrades the legibility of digital types. To maintain typographic quality in an aliased image environment, the design of readable digital typefaces requires rational, technical considerations as well as intuitive, artistic processes. The graphic functions of typefaces in electronic publishing also require rational structuring. Documents can be more effectively designed when typographic variations of weight and style are integrated into a systematic design family.

OMAGGIO A GRIFFO
One by one, each seriffed black figure
is transfixed in the luminous white field.
As the gaze travels across the page,
it goes like the wind on a summer night,
Blowing the clouds in their atmosphere,
Light in the face of the full moon,
and dark in the depths of the starry sky.

In designing the Lucida typefaces for laser printers, digital typesetters, and CRT screens, we found inspiration in the work of Francesco Griffo, a Renaissance typeface designer who flourished at the end of the 15th century during an era of profound change in the technology of literacy.

At a time when other type-founders were attempting in vain to copy manuscript writing hands, Griffo was the first punch-cutter to actively explore the design possibilities of the en-

graved, typographic letter. He created letterforms that were no longer handwriting, but that nevertheless stemmed naturally from principles inherent in the alphabet. The types he cut for the Venetian printer Aldus Manutius profoundly influenced the history of typography [Mardersteig69] [Morison73].

The fundamental problem that Griffo faced was how to maintain clarity and vivacity of the text image in a radically changed imaging technology. We face the same problem today.

1. Transformations of Letterforms.

1.1 From Ductal to Sculptal to Pictal.

Griffo helped transform the ductal handwritten letter of the scribe into the sculptal typographic letter of the printer. The analog typographic letter became the publishing standard for five centuries, but it is now being replaced by the pictal electronic letter in digital printing and electronic publishing. From the reader's point of view, the main flaw of digital typography is the degraded appearance of the typefaces [Bigelow81, 82].

1.2 Aliasing.

Current digital screens and printers lack resolution sufficient to render traditional analog letterforms adequately. A digital letter is typically produced by sampling an analog letter. Low and medium resolution devices like CRT screens and laser printers do not provide enough samples in a letter image to reproduce all the information in the original design. "Undersampling" causes loss of high-frequency information and "aliasing", a form of digital noise. The contours of an aliased letter are disrupted by "jaggies"; its proportions, weight, and spacing are distorted, and its fine details obscured [Bigelow,Day83].

To understand how to design letters for rasterized reproduction in the one bit per pixel technologies common today, it is helpful to consider the common ad hoc methods of ameliorating aliasing in letterforms. These are bitmap editing and outline deformation.

1.3 Bitmap Editing.

A letter is first scan-converted to a raster from an analog image or a digital outline. Then a designer "edits" the resulting raster image by adding, deleting, or rearranging pixels. In this process, the designer's intuitive, internalized model of what the letter

image should be is mapped onto the actual raster image, modifying the arbitrary output of an electro-optical or algorithmic process. This is often effective because the designer actually *sees* what she is doing, and thus intuitively tunes the image to the characteristics of the human visual system in accordance with knowledge of canonical letter shapes.

Bitmap editing has the disadvantage of being a low-level, local manipulation of the letter image. An alphabet design also contains global information that bitmap editing cannot directly address. The alphabet structure remains a concept in the mind of the designer, but it is not a part of the data representation.

1.4 Outline Deformation.

A higher-level method of ameliorating aliasing is to deform letter images globally throughout an alphabet before scan-conversion. When letters are represented as outlines, the points defining the outlines can be adjusted in relation to the output raster so that certain letter features will fall nicely on raster values. For example, the edges of all vertical stems in an alphabet could be deformed to fall on integer values of the raster, and constrained to have the same pixel thickness [Karow83].

1.5 Noise & Signal.

Bitmap editing and outline deformation can have similar results, and it is possible that they are related in an abstract way.

Bitmap editing appears to be a way of rearranging the aliasing noise in the rasterized letter image. Because editing does not increase resolution, aliases remain from under-sampling, but their spatial positions in the image have been moved.

In the frequency domain, bitmap editing may be a way to shift the frequencies of the aliasing noise further from the fundamental frequencies of the signal. The noise would then mask perception of the signal to a lesser degree. The letters remain distorted, but appear less so because certain lower frequency components (e.g. stems) have a more regular relationship to the raster.

These are merely conjectures, but efforts to optimize digital type could benefit from a rigorous analysis of the effects of scanning, editing, and deformation on the frequency spectra of letterforms at various resolutions. Typefaces are a special kind of image that could benefit from refined methods of

anti-aliasing, especially on displays with multiple bits per pixel [Kajiya,Ullner81] [Dippe,Wold85].

Deformation of outlines appears to accomplish the same thing as bitmap editing, though prior to scan-conversion, by deforming the original image to match more closely the periodicity of the sampling grid. Major letter features become aligned with the raster, and thereby exhibit less obvious distortion.

In both cases, important information about the structure of the alphabet is missing from the basic font data, whether raster or outline, and must be supplied from an external source (a designer). An explicit model of alphabetic structure could support automatic identification of letter features and their parameterized deformation to optimize scan-conversion of letterforms.

It may be that such a model could take the form of a more elaborate data structure for each outline font, or perhaps canonical models could be developed for the kinds of alphabet design: either by style, i.e. seriffed, sans-serif, etc.; or by class, i.e. Latin, Greek, etc. Much of the research in this area is currently embedded in proprietary research or commercial systems [Plass] [Sheridan] [Warnock].

1.6 Rationalization.

To facilitate digitization and enhance image quality, alphabet designs for electronic printing and publishing should be more explicit and more rationalized than traditional analog typefaces. A *structural model* of the alphabets should be communicable both to designers editing bitmap fonts, and to algorithms performing automatic transformations on digital outlines.

An outline representation with precise specifications of proportions, parameters, letter parts, and other design features is one way to implement alphabetic structure. Philippe Coueignoux has described one approach to a "syntactic" font description [Coueignoux75]. A different approach to a parameterized, structured alphabet design, based on a "pen-drawing" model rather than outlines, is described by Donald Knuth [Knuth80].

1.7 Tuned Features.

The features of letterforms intended for digital printing and display should in general be tuned to the marking characteristics of digital devices. This is difficult because different devices

may have contradictory effects, and new kinds of technologies are continually being developed.

1.8 Systematic Typography.
Typeface design is not isolated from the literate culture that uses printing systems. Electronic document production has certain typographic requirements that are different from those of traditional publishing; these will proliferate as the digital technology becomes more prevalent. Among the present needs are simplicity and clarity in typeface families, so that authors and editors may achieve greater fluency in the symbolic language of typographic signs, without protracted study. Typographic variation should be coherent and systematic.

2. The Design Concepts of Lucida

Following these observations and conclusions, we designed the Lucida family of typefaces to provide, at the perceptual level, acceptable legibility in an aliased image environment, and, at the semiological level, a functional system of typographic variations.

Although types are designed at a large size (the master outline characters of Lucida are digitized at an em square of 168 x 168 mm), text is read at small sizes. In designing Lucida, we worked at several levels of the letter image.

2.1 Form, Pattern, & Texture.
At the large size of the master design, a letter form is comprised of sculpted contours delineating dark forms and light counterforms. At a middle size of headlines, letters in combination make patterns out of the quasi-symmetries of repeated forms. At the small size of text, a complex texture emerges from the interaction of the letter features en masse.

We design the features of a typeface at the level of forms, but the character of the face emerges at the level of texture. For the designers, there are often surprises when a type design is first proofed: rational decisions about formal properties turn out to have irrational effects when the texture is perceived. This is part of the excitement of typeface design.

In its features, Lucida is intended to be a font-independent design. This is not the same as a device-independent font. A type design is a visual concept, whereas a font is an implementa-

tion of that concept in software or hardware. Traditional typefaces were tuned to the typefounding and printing processes. We sought to tune the letterforms of Lucida to digital image processing and reconstruction.

2.2 Weight.

An index of the weight of a normally proportioned typeface is the ratio of the thickness of a straight stem to the height of the lower-case 'x'. The shade of the gray texture of a face is termed "color". Our survey of several traditional and popular text typefaces showed a variation of stem to x-height ratios from 5:1 to 6:1. Types with ratios toward 5:1 are darker; those with ratios toward 6:1, lighter.

In laser-printing, the polarity of the marking engine becomes an important factor. White-writing engines tend to erode the contours of the letterforms, lightening the color of the text. Black-writing engines tend to spread the contours, darkening the text.

Another factor is the use of laser-printer output as masters for offset-lithography or photocopying. These processes further darken or lighten the text image.

On screens, the writing spot which reconstructs the bitmap letterforms also changes the weight of the text image. The perceived weight of screen text is influenced by the intensity contour of the spot and the size of the spot in relation to the resolution of the raster. The reconstruction filter effects are strongest at the pixels along the contour of a letterform. Small sizes and lower resolutions, where the contour is a greater part of the total image, are more strongly affected.

Numerically, the weight ratio of a face necessarily varies from size to size because stems and x-heights are rounded-off to integer pixel values at each raster size. We examined the amounts of error in ideal weight ratios caused by round-off at common sizes and resolutions.

These observations led us to estimate that the weight of the text image seen by the reader would on the average vary about 10% from the original design, and in the worst cases by as much as 25%. To make the typeface resistant to extreme variations in color, we designed the normal weight of Lucida with a stem to x-height ratio of 5.5 to 1.

2.3 Contrast.
Contrast is the ratio between the thick and thin parts of letters. Serifs, hairlines, and joins are thins; vertical stems, curved bowls, and main diagonals are thicks. The contrast of traditional text types ranges from a high of 5:1 to a low of 2:1. The high-contrast faces appear delicate and brilliant; the low-contrast faces, sturdy and solid.

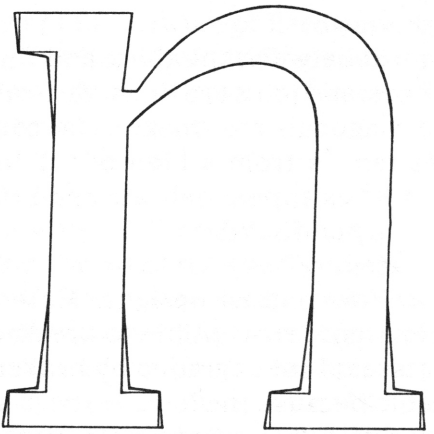
High contrast faces are believed to be more difficult to read than medium and low-contrast designs. Moreover, thin hairlines and serifs are more susceptible to breakage and erosion by printing processes. Text degraded by broken thins is especially objectionable because the letterforms lose connectivity and become more difficult to discriminate. Marking effects that change weight change contrast even more, because erosion or expansion of thin hairlines is proportionally greater than for thick stems.

To prevent of loss of hairlines and serifs on white-writing engines and bitmap screens displaying black text on an illuminated background, we chose a low contrast of 2:1 for the basic Lucida seriffed designs. This decision in favor of robustness also influenced the design of joins and serifs.

2.4 Joins.
Black-writing printers and reverse-video displays increase the thickness of thin elements. In particular, the white triangular counter-forms produced where an arch joins a straight stem, as in an 'n', tend to be filled in when letter contours are emboldened. Therefore, when joins are kept sturdy to prevent erosion by white-writing printers, counters are susceptible to clogging by black-writing printers.

Our solution to this antinomy was to branch the joins relatively deep on the stems, so that the triangular counter-form of the master design has a generous area. Hence, even when the counter is filled to some degree, it remains open enough to be acceptable. After we had designed this feature in Lucida, we discovered that Fleischman, an 18th century punch-cutter, used a similar technique in cutting small sizes of types intended for journal publishing [Carter37] [Enschede08].

To further prevent clogging, we reduced the thickness of the stem close to the join by making the segment of the stem edge closest to the join cut into the stem at a slight angle. The amount



[1] Outline of Lucida Roman 'n' showing details of the simplified polygonal serif structure and enlargement of the counter area where the arch joins the left stem. The chamfered serifs and tapered stems can be resolved at high resolutions, but the underlying slab serifs and straight stems result at low resolutions. The stem is narrowed at the join, to prevent the counter from clogging with toner at lower resolutions on black-writing printers. The gap can be narrowed for white-writing printers and higher resolutions. These details are seen here at a large size at the level of form, but they are intended to be seen at a small size at the level of texture.

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[2] The eight basic styles of Lucida, composed in "key-words" made up of round, straight, diagonal, and composite letterforms: Roman, Italic, Bold, Bold Italic in seriffed and sans-serif styles. At a small size, in this case 8 point at 300 lines per inch (= 33 pixels per em square), the formal details become invisible and the textural qualities of the design dominate the image. The relationships between roman and italic, normal and bold, seriffed and sans-serif become subtle but significant.

of cut is determined by the position of a single point. When the join is in danger of clogging at small sizes, this point can be shifted toward the interior of the stem and the cut widened. When the stem should appear straight at large sizes, the cut can be narrowed.

2.5 Serifs.

Our design experiments showed that long, thick serifs give a typeface a stolid appearance and a dark color. We wanted thick serifs to resist erosion, but we didn't want too dark a color. Accordingly, we reduced the total area of the serifs by abbreviating their lengths to one-half of the stem thickness.

Serif shapes also posed problems. When letters are reduced to coarse bitmaps at low and medium digital resolutions, bracketed serifs are reduced to slab serifs. When letters are represented as outlines, curved brackets are complex details that can require extra time to digitize, more space in storage, and more time to scan convert.

A slab serif would have simplified the alphabet design without appreciable loss of elegance at low resolution, but at high resolution, the slabs would have seemed monotonous. We chose a middle path, chamfering the serif and stem with slight diagonal taperings. At low resolutions, these serifs can be rounded-off to simple slabs, but as resolution increases, the chamferings provide variations in weight and thickness that enliven the printed texture.

These polygonal serifs can be compactly and precisely represented by vectors. In a font format that provides for adjustment or deformation of letter features to enhance scan-conversion, the polygonal serifs are more diagrammatic than absolute, because the points on the vertices can be moved by algorithm or by designer specification to enhance the appearance of the resultant bit image.

2.6 X-height.

The x-height (height of lower-case 'x') of a typeface is an index of the apparent size of a typeface. Most of the shape information in the lower-case alphabet is carried by those parts of the letters that lie between the baseline and the x-line. Typefaces with large x-heights look bigger than those with small x-heights, even when the actual body sizes (total cell height from bottom

[3] Lucida seriffed lower-case *'a'* at three resolutions corresponding to 8, 10, and 24 point fonts on a 300 line per inch laser printer. The effects of under-sampling are plainly evident. At left, the lowest resolution shows a strongly aliased image with "jaggies" that disrupt the curved and diagonal letter elements. At right, the highest resolution still shows noise along the contours. When these idealized bitmaps are reconstructed as actual images by a laser printer, the sharp images of the stair-steps are smoothed, but some distortion of the forms remains.

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[4] ASCII character sets for the eight basic styles of Lucida, augmented with ligatures and diacritics. The stylistic variations also apply to the non-alphabetic characters, so that the semiological contrasts are consistent throughout a given typeface. Note that the sans-serif italic is a true cursive style, rather than an oblique distortion of the roman. This gives the sans-serif italic greater vivacity, and maintains its relationship to the seriffed italic.

of descender to top of ascender) are the same.

Low-resolution systems entice the designer toward large x-heights because the complex middle portions of the lower-case need more resolution than the relatively simple ascenders and descenders. However, if the ascenders and descenders are reduced too far, the complex lower loop of the humanistic 'g' will be distorted, and the shapes of other letters ('h' - 'n', 'b' - 'p') will become indistinguishable from each other, destroying the legibility of the face. Thus, there is an upper bound to the size of the x-height.

The x-height of Lucida is 52% of the body. This allows more detail to be devoted to the lower-case letter shapes, and permits Lucida to pack a relatively large amount of legible text information into a relatively small area. Lucida set at 9 point seems as large as many other faces at 10 or 11 point. Where page space is limited and text economy important, this increase in apparent size is a definite advantge. However, where economy of space is not crucial, we prefer to see Lucida composed with extra points of "leading" (white space) between lines, to give the page a more open and relaxed texture.

2.7 Fitting.

The positive (black) and negative (white) shapes in a letterform are equally important. Traditional typefaces are fitted so that the spaces between letters are visually equivalent and harmonized with the white counters inside the letters. Aliasing distorts the interletter white spaces as much as the black shapes of the letters, causing an irregular texture with dark collisions of some characters and empty voids between others.

In advertising typography, tightly kerned letter spacing draws attention to texts that are otherwise empty of content. However, when this kind of spacing is attempted on low resolution printing systems, round-off error of letter widths creates an objectionable, splotchy texture.

The best printed books of the last 500 years have typefaces that are regularly, harmoniously, and often openly spaced [Tschichold66]. We followed these models when fitting the Lucida designs for laser printer resolutions. At typesetter resolutions, where tighter fitting can be accomplished without losing a regular rhythm, Lucida can be more closely spaced.

2.8 Capital Height.
Our traditional capital forms were developed by the Romans, and our lower-case (minuscules) by Carolingian scribes. Capitals and lower-case were separate alphabets until the early 15th century, when they were first amalgamated into a single duplex alphabet by the Florentine humanist and scribe, Poggio Bracciolini. At the end of that century, Francesco Griffo fine-tuned the relationship between typographic capitals and lower-case by reducing the relative size of the capitals.

Documents printed by laser printers often are dominated by capitals, usually for retrograde reasons left over from monocase terminals and printers. Following Griffo's lead, we made the Lucida capitals slightly shorter than the ascenders of the lower-case so that capitals would not be too emphatic and distracting when used heavily in a text. As well as reducing their height, we also gave the capitals slightly narrow proportions to provide even greater space economy when capitals are used extensively in a document.

We also observed that weight differences between capitals and lower-case are often exaggerated at low resolutions, when a one pixel increase in stem thickness will make the capitals seem much darker than the lower-case. Therefore, we made the capitals similar in weight to the lower-case to keep the alphabets harmonious at lower resolutions.

The design of capitals is also affected by the orthographies of different languages. De-emphasized capitals are often preferred for German language texts that make extensive use of capitals. However, we also anticipated that some French and English typographers would request more robust capitals, in keeping with certain national printing traditions and cultural views. We therefore designed an alternate set of capitals that are heavier in weight, especially for use on higher-resolution devices.

3. The Structure of an Extended Family

3.1 Teleology.
The history of typography shows a tendency for typeface designs to become united into families. Capitals and minuscules (lower-case) were united in the early 15th century; roman and italic in the 16th century; normal and bold weights in the 19th century. The first typeface family to include both seriffed and

sans-serif alphabets was Romulus, designed by Jan van Krimpen in the 1930s.

3.2 Dimensions of Typographic Space

Lucida continues the historical trend toward extended design families by structuring several letterform styles in one family: roman vs. italic; normal vs. bold; seriffed vs. sans-serif; proportional vs. mono-spaced; Latin vs. Greek. The family is thus a system of oppositions which can be thought of as defining a multi-dimensional space of typographic variation.

These contrasting variations are precisely aligned in their vertical letter proportions and standardized in weights. A change along one dimension leaves most other characteristics of the typeface unaltered, with the exception of letter widths. Widths are similar, though not quite identical between roman and italic, and seriffed and sans. The bold weights are proportionally wider than the normal weights.

3.3 Semiology of Type Styles.

Each graphic typeface variation can be used to signify or *mark* some semantic aspect of the text. Roman may be used for normal text, italic for differentiation, bold for emphasis, bold italic for emphatic differentiation, sans-serif for technical text, script for casual notes, and so forth.

Type styles used as signifiers are part of the "passive vocabulary" of typographic literacy; readers understand them, but type variations are not necessarily part of the "active vocabulary" of every author. Like other languages, a graphic language of formal variations requires practice for the user to become fluent. Initially, one follows conventional styles of typography, but more imaginative expression becomes possible as one becomes more familiar with the medium.

The harmonization and simplification of the Lucida family is intended to make the Lucida typefaces easier for authors to use intuitively. When typographic documents are formatted with systems like TROFF, TeX, and Scribe, graphic variations should be clear and comprehensible to the author as well as to the reader. Clarity and simplicity of variation makes it easier for an author to use typefaces expressively and powerfully.

3.4 Modularization.
Another effect of harmonization is to make typefaces easier to implement. Within each Lucida face, many elements such as stems, serifs, and bowls are repeated. Should it be necessary to save space in a font implementation, characters can be represented as assemblages of component parts rather than separate characers. Across the family, different designs may also share certain features. Seriffed and Sans-serif faces of the same weight and stress share the same stems and outer contours of bowls. The entire Lucida family could be further compacted by exploiting these similarities.

Modularization of design also made it easier to produce the faces, both in outline and in raster format. More often than not, the principal advantage of rationalization and modularization was simply a precise understanding of the design parameters. This was often reasurring when we were caught in the coils of the magnitude of the actual production. The Lucida family currently includes 1,500 outline masters and 12,000 raster characters, with more in production. In the midst of this daunting multiplicity, a coherent design structure that could be expressed in logical and numerical relationships made it easier to remember, communicate, and record what a given letter image or group of images was supposed to look like at any given size on a variety of displays.

3.5 Screen Fonts.
The principles that shaped the Lucida designs for printers similarly influenced the design of bitmap versions of Lucida for CRT displays. At screen resolutions of 75 and 100 lines per inch, all sizes of the Lucida fonts required bitmap editing.

From 6 to 22 pixels per body, the fonts were mainly constructed by hand, using a bitmap editing system. At these low resolutions, there are so few pixels in each letterform, and the position of each pixel is so crucial, that only the experienced eye of the designer can make an optimal judgement. For sizes of 24 pixels per body size and greater, the fonts were produced in two stages. Digital spline outlines were first deformed to the given raster, using the Ikarus software system. This provided a general idea of the charactristics of the font at a given size. The resulting rasters were then hand-edited to optimize the fonts on the screen.

Because of their low resolution, screen fonts cannot be exact reproductions of their higher resolution counterparts. We wanted the screen fonts to be usable in "WYSIWYG" systems along with Lucida on printers, but also to be useful on their own, when optimized for legibility on the screen without the procrustean distortion to match spacing values of higher resolution devices that the simple-minded WYSIWYG systems usually demand. To emphasize that the screen fonts can exist as independent entities, we christened them with the name Pellucida, which connotes that the designs are related to Lucida, but optimized for "pel" based screen displays.

4. Conclusion

Typography holds a particular fascination for the inquiring mind, and this is nowhere more evident than in the realm of electronic printing and publishing. Typography is abstract, achromatic, and two-dimensional, yet it constitutes a complete aesthetic microcosm accessible to the literate intellect. Typefaces exist only to serve language, yet their art is as subtle as music or painting. The forms of the letters are intuitive and mystical, yet they are ruled by numerical principles and systems of measurement and proportion. The patterns of the alphabet are arbitrary and historical, yet they reveal a complex symmetry and an intricate evolution. The texture of a page is completely visible, yet how it emerges from the interaction of its myriad components remains obscure.

We designed Lucida to meet the practical needs of contemporary electronic publishing, but it was for us also an exploration of that aesthetic realm at the intersection of science and art. Because Lucida was, to our knowledge, the first original typeface family produced for digital printers and displays, we necessarily based much of its design on principles more than on precedents. Some of those principles had to be invented as we worked on the design and encountered puzzles for which there were no ready answers. Yet the design is not completely novel, nor can it be wholly reduced to logic, for many of the principles were distilled from alphabets created in previous eras by visionary artists who bequeathed us their letterforms but not their reasoning.

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